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AIR/GROUND SIMULATION OF TRAJECTORY-ORIENTED OPERATIONS WITH LIMITED DELEGATION

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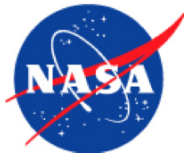
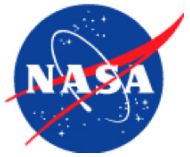
Summary



- **Simulated airspace operations with Continuous Descent Arrivals (CDA), automated arrival management, airborne spacing, controller tools, and data link**
- **Varied two flight deck conditions:**
  - *(1) with airborne spacing*
  - *(2) without airborne spacing*,
- **over three ground-side conditions:**

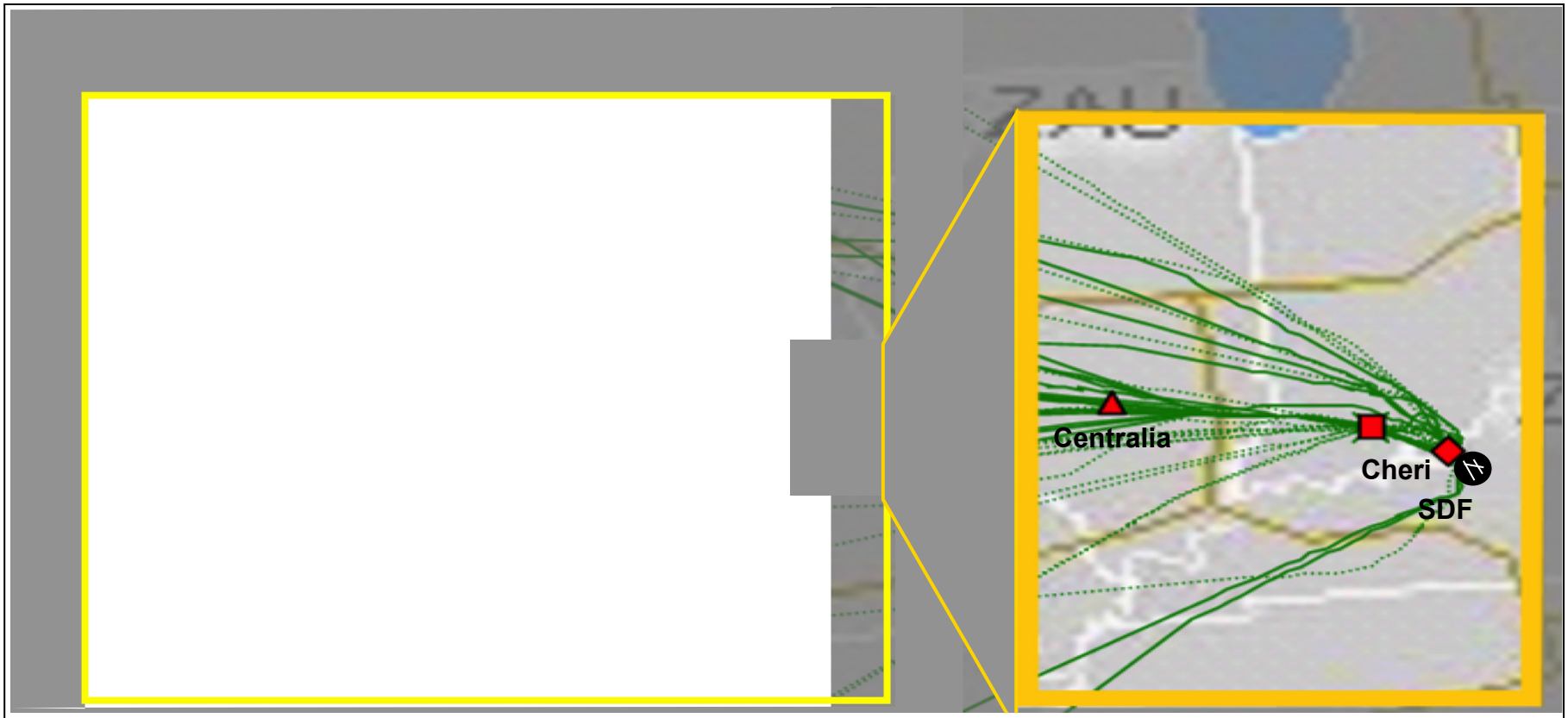
  Automated Arrival Management System with
  - *(1) current day controller displays*
  - *(2) advanced ATC scheduling and spacing tools, and*
  - *(3) the same tools integrated with controller pilot data link communication*.
- **Analyzed controller workload, safety, arrival time errors, inter-arrival spacing, energy management**

Outline



- **Background: Merging & Spacing at Louisville**
- **Trajectory-Oriented Operations with Limited Delegation (TOOWiLD) Concept of Operations for Managing Arrivals**
- **Test Airspace**
- **Experimental Design**
- **Results**
  - Feasibility: Workload, safety, CDA success rate
  - Runway throughput: Inter-arrival spacing with and without airborne spacing
  - Accuracy/predictability: Arrival time errors at the threshold
  - CDA efficiency: Energy management along the CDA
- **Concluding Remarks**

Background: Flight Deck-Based Merging & Spacing (FDMS) Concept with Airline-Based Sequencing and Spacing (ABESS) at SDF



•M&S En Route Operations

•Inbound aircraft are "preconditioned" using GOC speed advisories based on sequence and spacing at en route merge fix. Spacing advisories may also be assigned. Advisories are sent to the flight deck using ACARS.

•Little-to-no ATC involvement.

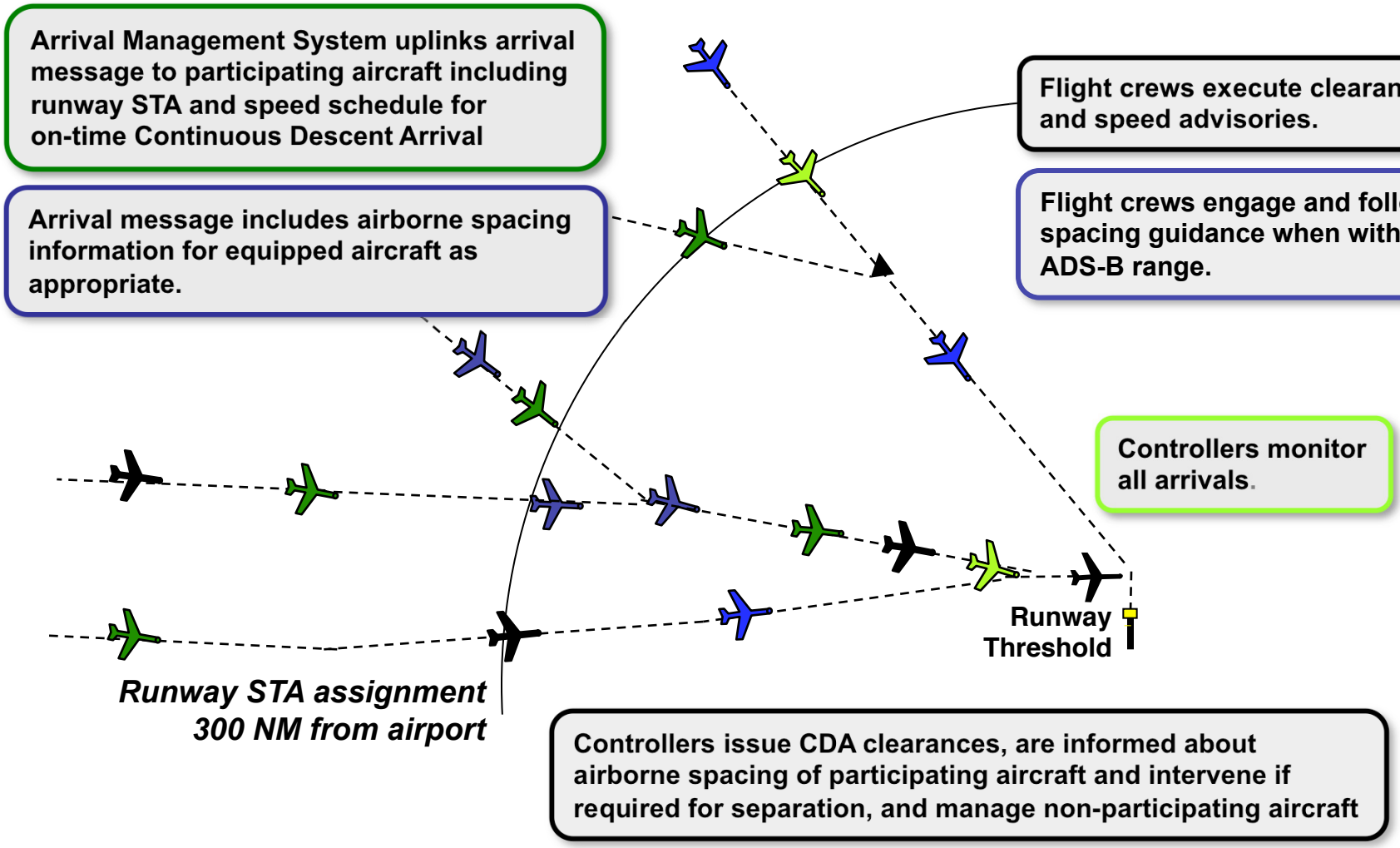
M&S Arrival Operations

•Aircraft that are within ADS-B range may engage airborne merging and spacing.

•"Preconditioned" SDF arrivals are cleared by ATC for CDAs.

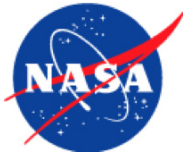
•Little-to-no ATC involvement.

TOOWiLD* Concept of Operations for Managing Arrivals During Simulation



*TOOWiLD: Trajectory-Oriented Operations With Limited Delegation

ACARS arrival information message

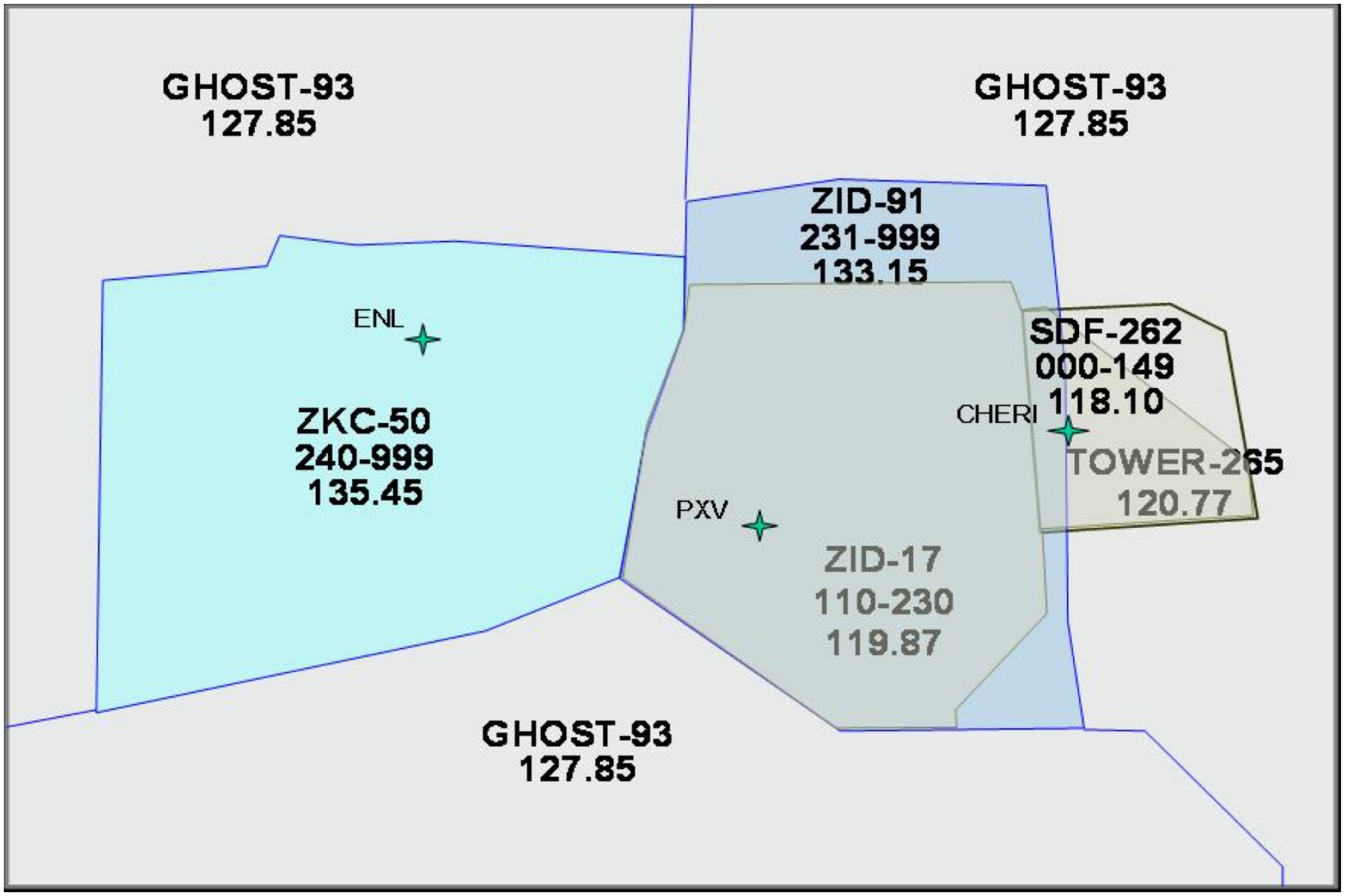


- **At the STA freeze horizon (300 NM from the airport) an arrival information message is sent by the automation via ACARS:**

"SDF ARRIVAL UPS913
17R AT 17:03:20 UTC
CRZ .78 DES .78/275
LEAD: UPS907
MERGE PT: CHERI
SPACING: 105 SEC"

"SDF ARRIVAL UPS913
17R AT 17:03:20 UTC
CRZ .78 DES .78/275

TOOWiLD Simulation Airspace



LOUISVILLE INTL-STANDIFORD D-ATIS 118.72

NASA

FOR SIMULATION PURPOSES ONLY

20 JUL 06

CHERI CDA ARRIVAL

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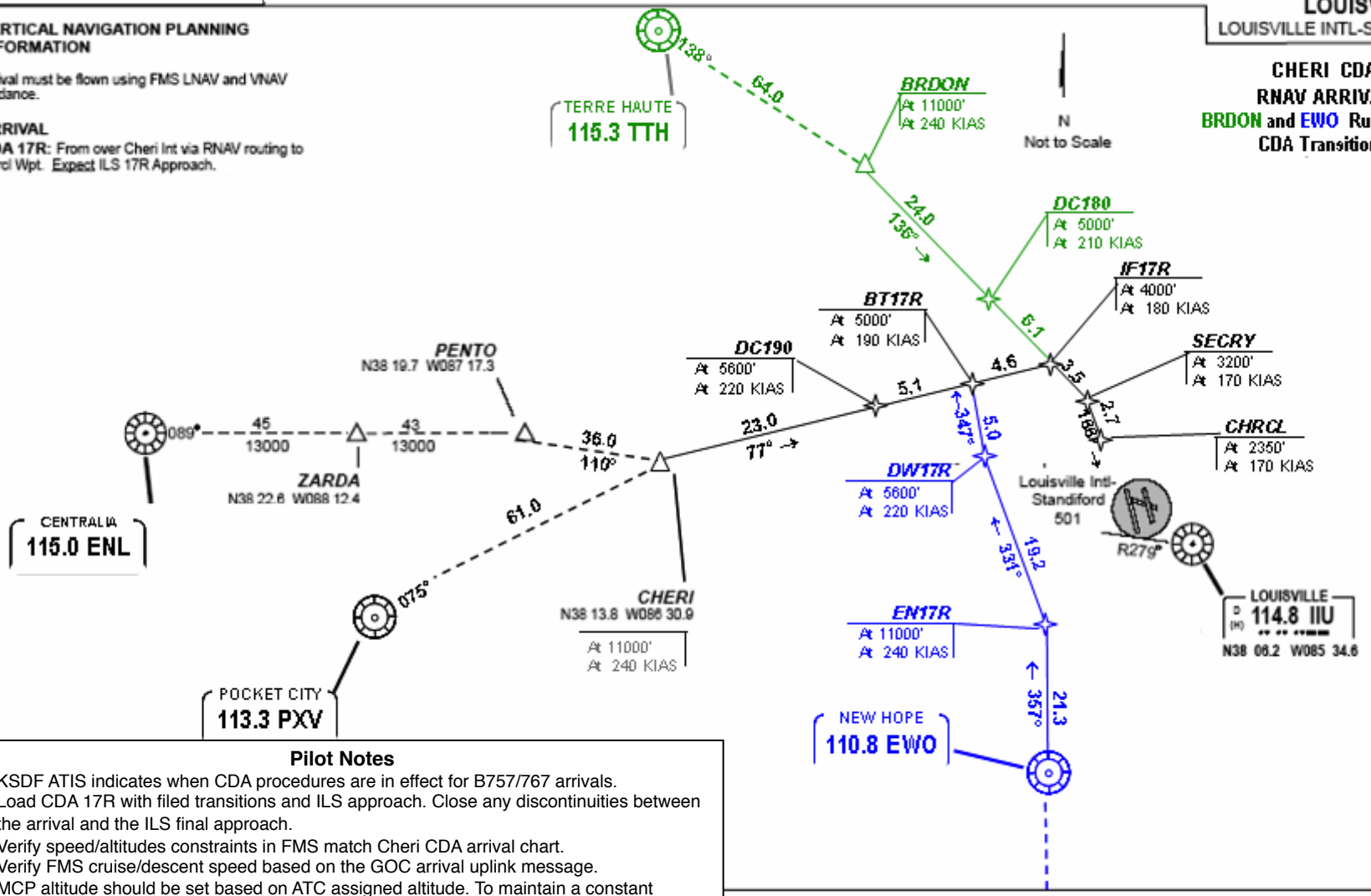
CHERI CDA
RNAV ARRIVAL
BRDON and EWO Runway 17R
CDA Transitions

VERTICAL NAVIGATION PLANNING INFORMATION

Arrival must be flown using FMS LNAV and VNAV guidance.

ARRIVAL

CDA 17R: From over Cheri Int via RNAV routing to Chrcl Wpt. Expect ILS 17R Approach.



Pilot Notes

1. KSDF ATIS indicates when CDA procedures are in effect for B757/767 arrivals.
2. Load CDA 17R with filed transitions and ILS approach. Close any discontinuities between the arrival and the ILS final approach.
3. Verify speed/altitudes constraints in FMS match Cheri CDA arrival chart.
4. Verify FMS cruise/descent speed based on the GOC arrival uplink message.
5. MCP altitude should be set based on ATC assigned altitude. To maintain a constant descent during arrival request lower altitude well in advance of any Top Of Descent.
6. Enter any ATC speed or route changes in the FMS and use power or speed brakes to re-acquire VNAV path. Flight level change or vertical speed should not be required.
7. For best VNAV path performance enter spacing algorithms speed into FMS prior to descent.
8. ARM approach after receiving ATC clearance for the ILS approach.

NOTE: The altitude constraints at individual waypoints are not ATC restrictions – they are point to initiate the speed slowdowns.

ATC CLEARANCE INFORMATION

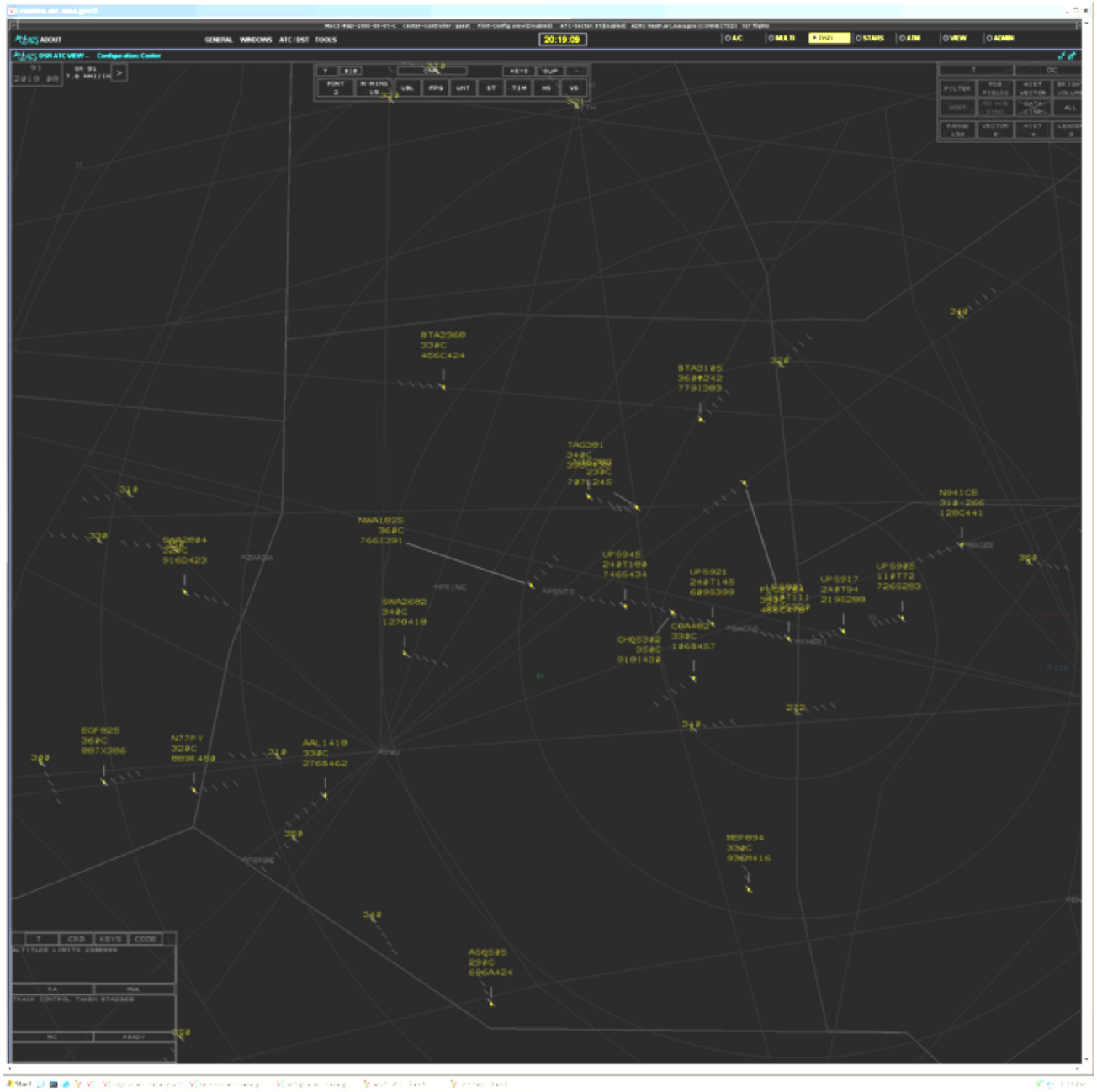
1. The filed ATC clearance is the CHERI2 arrival and ends at the IIU VOR
2. Clearance from Indianapolis Center will be a routing to CHERI and pilotís discretion to 11,000 feet. Indianapolis will make every attempt to begin the descent from the original cruise altitude.
3. Indianapolis will switch the flight to Louisville Approach in the vicinity of SACKO intersection.
4. Louisville Approach will give clearance for the CDA17R/35L arrival and pilotís discretion to 3,000 feet.
5. If clearance for the CDA and lower altitude is not received from Louisville Approach prior to CHERI, proceed via the filed routing to IIU VOR and maintain last assigned altitude.

CHANGES: New Page.

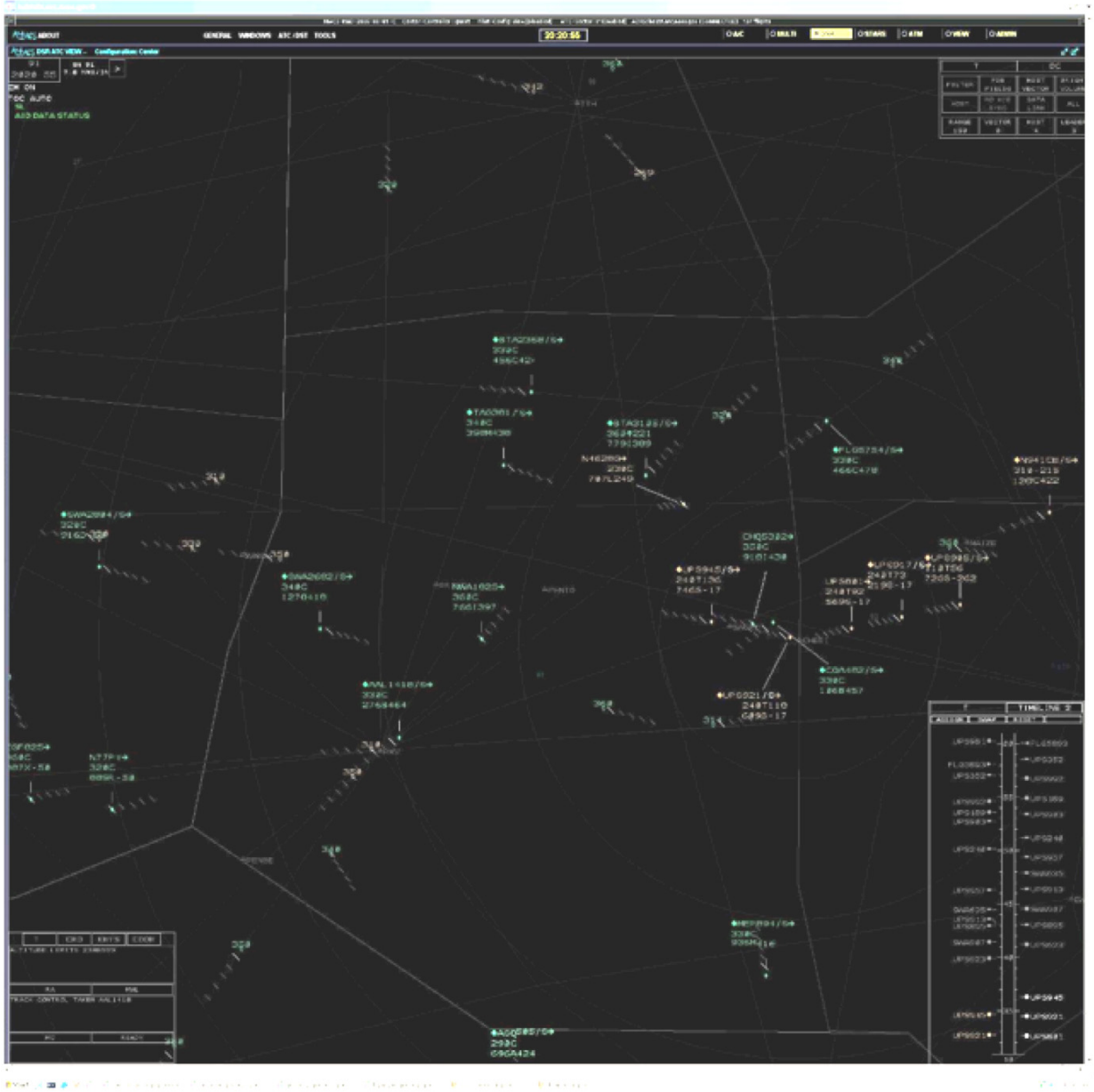
Experimental Design

- **September 2006 NASA Ames Research Center**
  - Airspace Operations Lab
  - Flight Deck Display Research Lab
- **Participants**
  - 4 radar certified controllers (3 ARTCC, 1 TRACON)
  - 8 airline pilots (3 current UPS pilots)
- **Traffic**
  - Extended UPS night-time arrival push mixed with day time crossing traffic (mixed equipage)
  - 2 Scenarios at high current day traffic levels
- **12 Data Collection runs**
  - Two basic Scenarios. each ~75 minutes
- **2 Flight Deck conditions:**
  - Current day FMS & ADS-B out
  - +Airborne spacing for 70% of UPS aircraft (Eurocontrol Co-space logic)
- **3 ATC Workstation conditions:**
  - Arrival management system with current day displays
  - +ATC tools for sequencing and spacing
  - +ATC tools integrated with data link

Current day controller display:

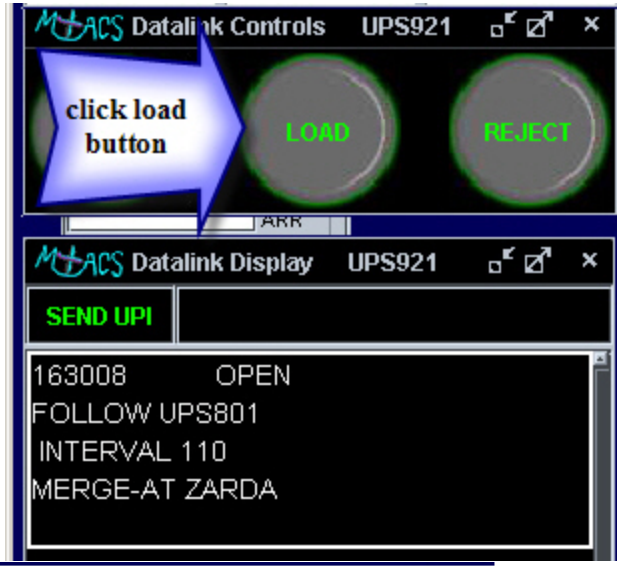


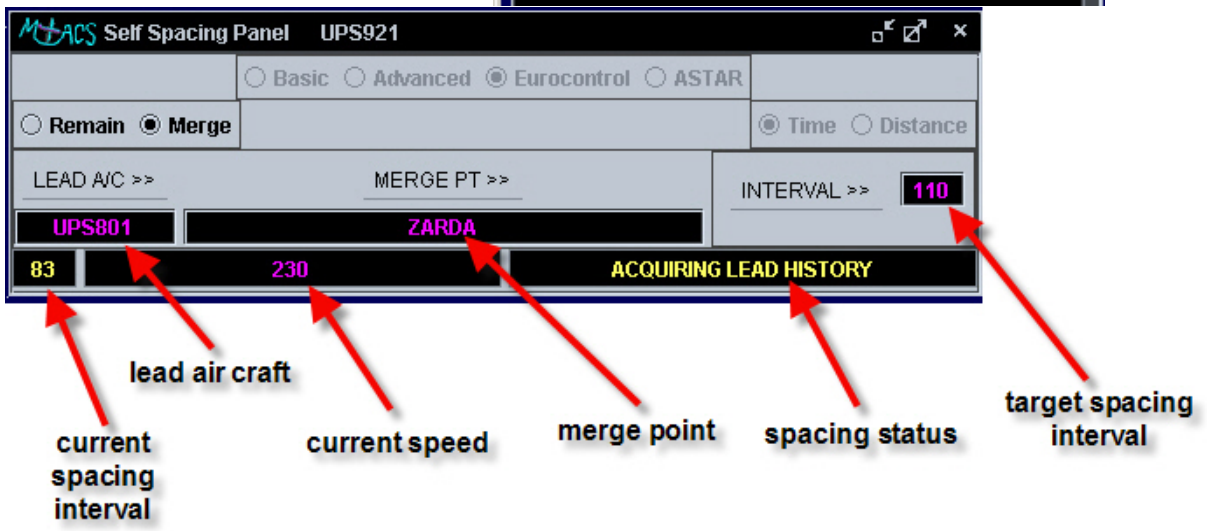
Controller Display with ATC tools and Controller Pilot Data Link Communication



Flight Deck Display

- **Receive, and load ACARS uplink merging and spacing Information**
  - Note that ownship is assigned a spacing of 110s behind UPS801 merging at ZARDA.





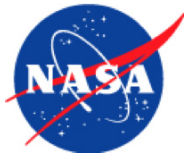
Flight Deck Display for Merging and Spacing

- **Monitoring current spacing on the Cockpit Situation Display**

6 Conditions simulating different Flight Deck and ATC equipage levels

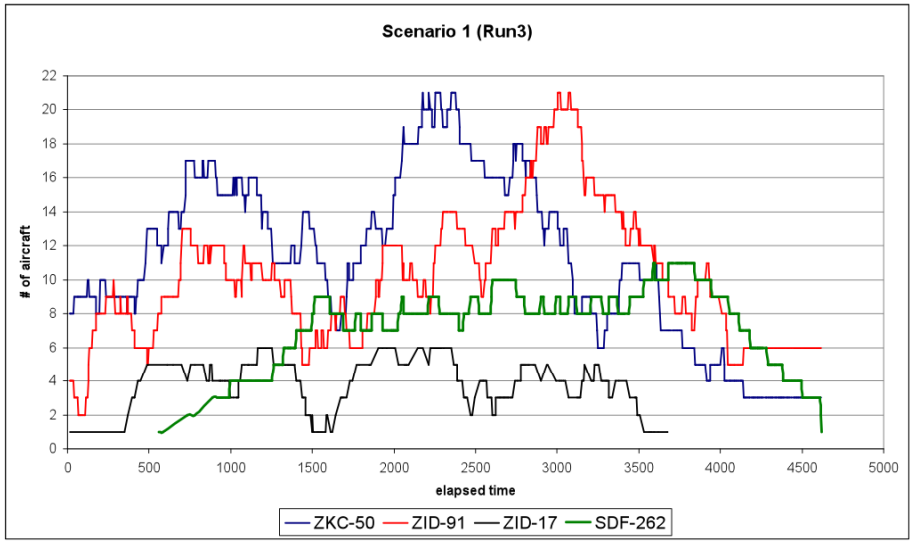
ATC equip. \ equip.	FMS (RNAV)	+ Airborne Spacing
Arrival Management System	**CDA's with automated sequencing & spacing**	**CDA's with automated sequencing & spacing and airborne spacing**
+ ATC tools	**CDA's with automated sequencing and spacing and time-based metering by ATC**	**CDA's with automated sequencing and spacing and time-based metering by ATC and airborne spacing**
+ controller pilot data link communication	**CDA's with automated sequencing and spacing, time-based metering by ATC and CPDLC**	**CDA's with automated sequencing and spacing, time-based metering by ATC and CPDLC and airborne spacing**

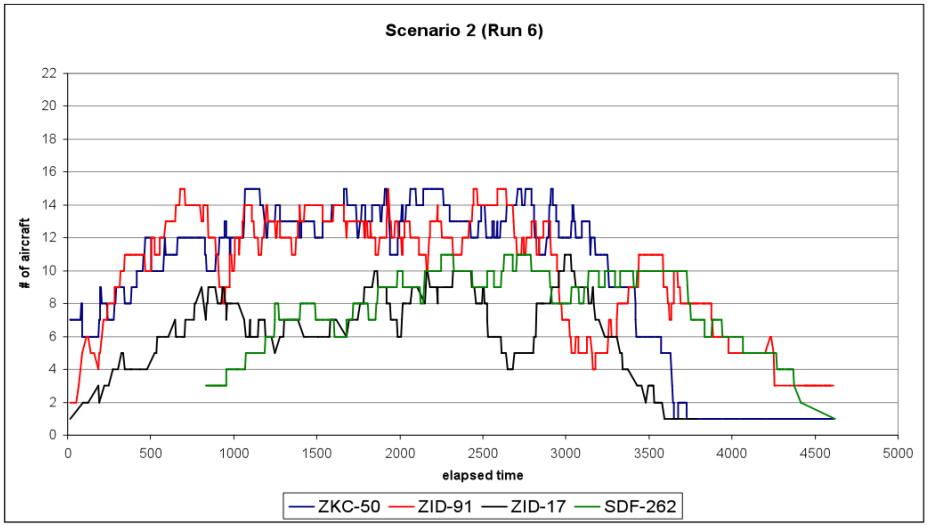
Result Summary

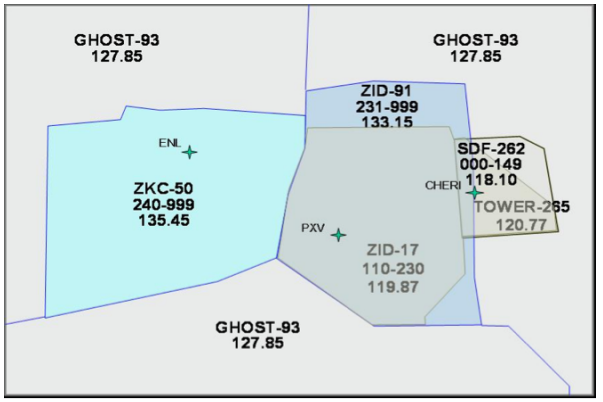


- **It seems possible to conduct continuous descent arrivals in high density airspace.**
  - Acceptable workload, safe, very little vectoring
- **Airborne spacing has positive effect on runway throughput and no negative impact on on-time arrivals.**
  - Better inter-arrival spacing, equal arrival time accuracy
- **The highly automated arrival management concept was very effective in all conditions.**
  - Good arrival time accuracy, and acceptable to both pilots and controllers
- **ATC tools reduce the mean error for non-participating aircraft and reduce the variability of all aircraft**
  - Higher arrival time accuracy with ATC tools
- **Energy management remains a primary issue to be addressed.**
  - Relative energy along CDA

Traffic Count (Scenario 1 and 2)







2 complex scenarios at high traffic densities.

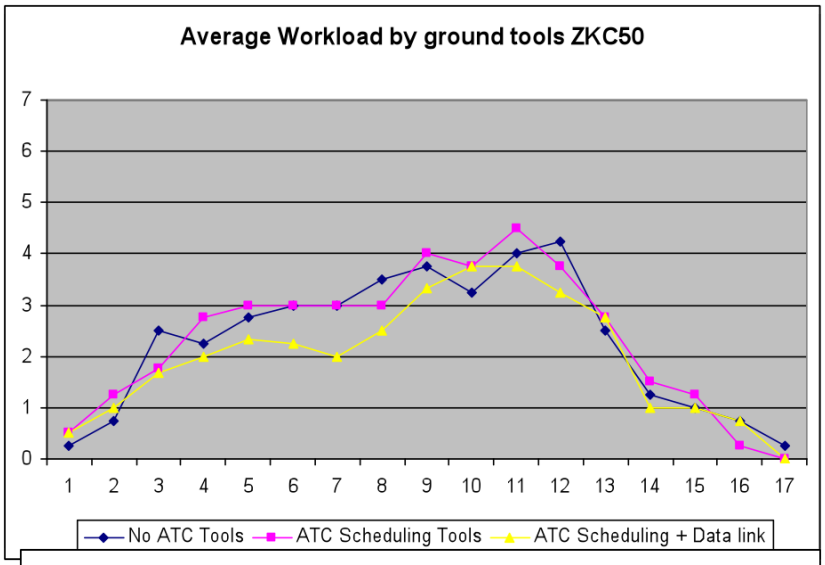
High altitude: 10-21 aircraft

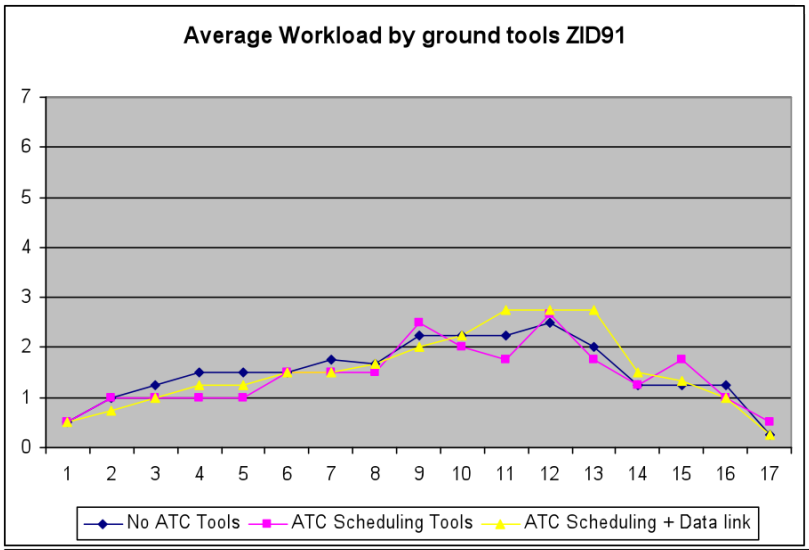
Low altitude: 5-10 aircraft

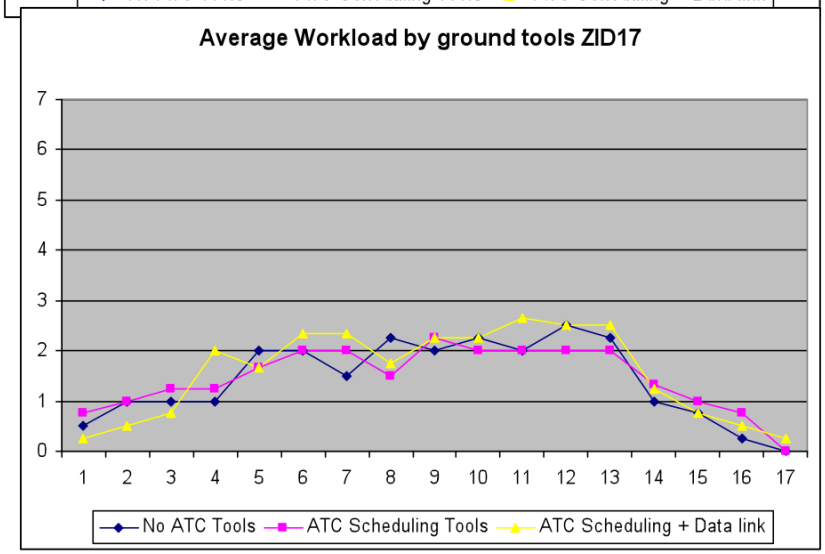
Approach: 7-12 aircraft

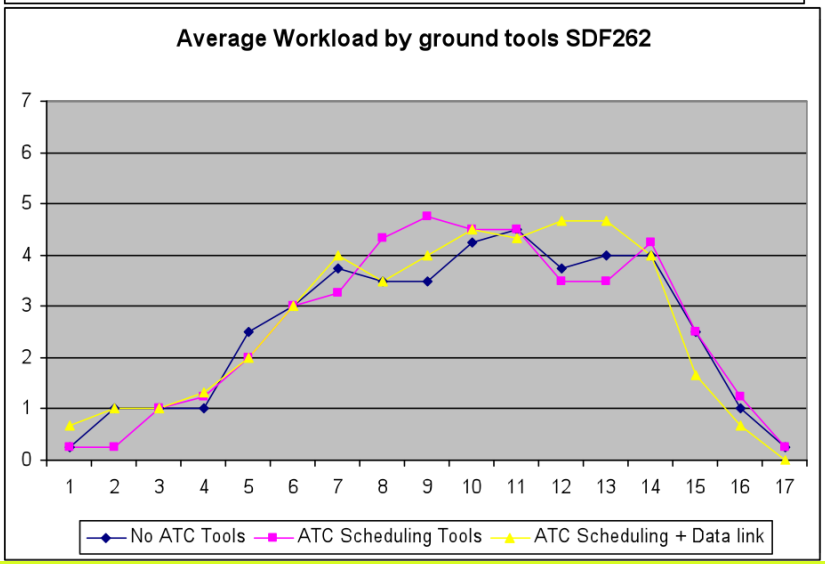
During these traffic conditions 96 % of arrivals flew the CDA approach routing and did not receive a heading vector below 11.000 feet

Controller Workload by ATC condition



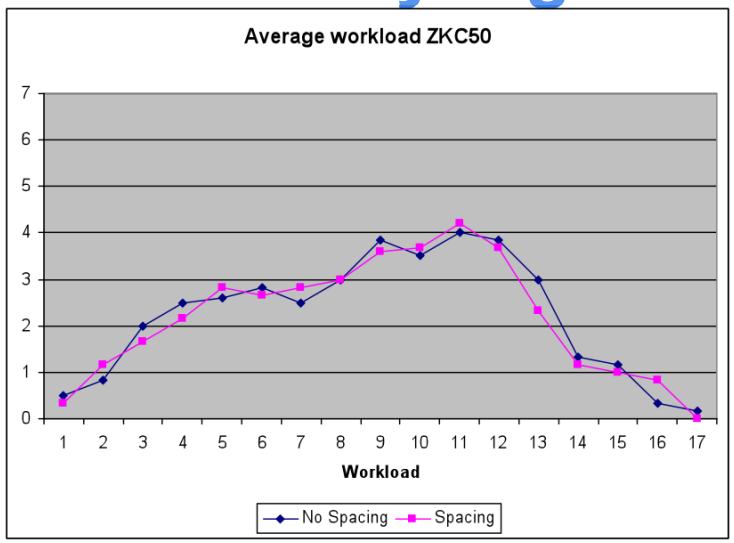


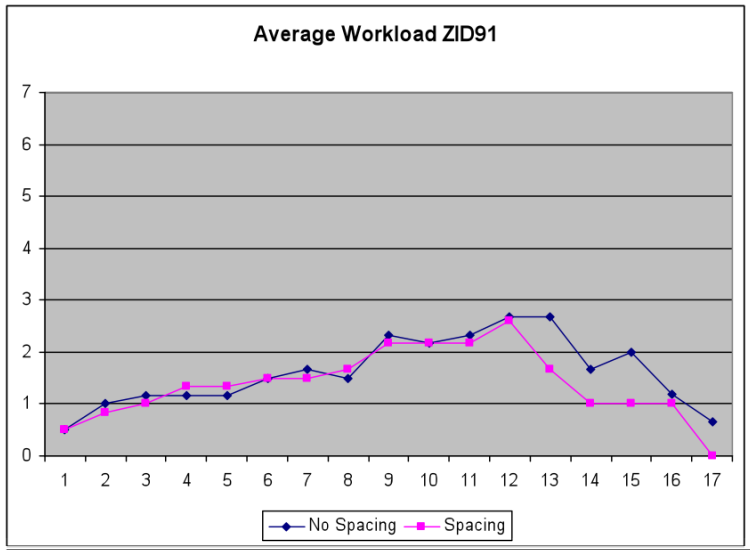


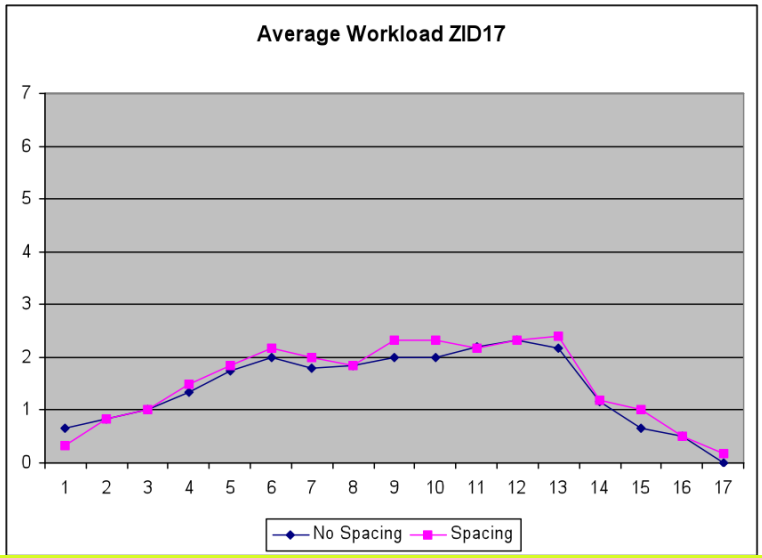


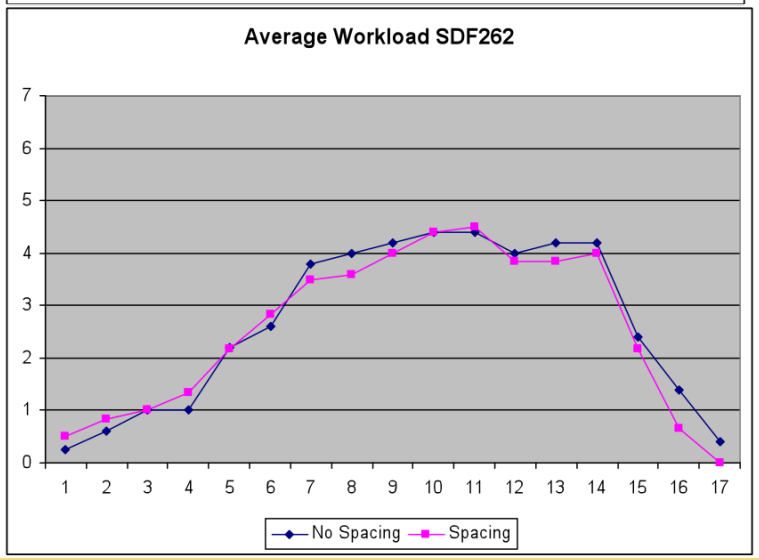
Controller workload was manageable and followed primarily traffic count.
No impact from ATC condition in mixed equipage environment

Controller Workload by flight deck condition









Controller workload was manageable and followed primarily traffic count.
No impact from airborne spacing in mixed environment

Safety

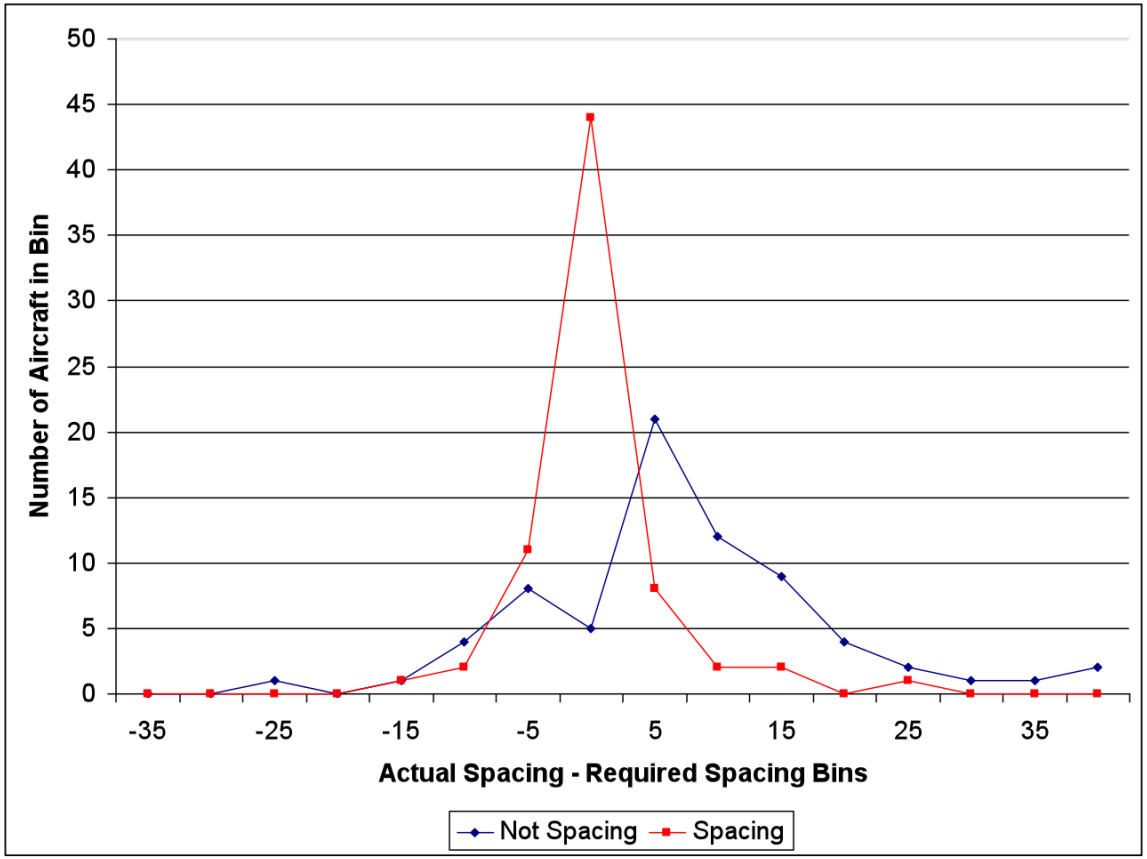
Separation violations by condition:

	FMS/CDA	+Airborne spacing	Total
Arr. Mgmt. Sys.	1 (1)	0 (3)	**1 (4)**
+ATC tools	0 (1)	1 (2)	**1 (3)**
+Data link	0 (1)	0 (1)	**0 (2)**
Total	**1 (3)**	**1 (6)**	

- **The 1st value refers to violations lasting for at least 12 seconds (RADAR sweep), the 2nd value to violations of less than 12 seconds.**
- **Only one Louisville arrival involved in separation violation**

All operations were considered safe by all participants. The observed separation violations were short and simulation related (multi-pilot errors)

Inter-arrival spacing at the runway - arrival peak -



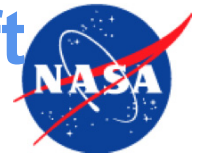
	Current day	Airborne Spacing
Spacing error (seconds)	**6.3 (15.6)**	**-1.5 (5.4)**

mean and variance of inter-arrival spacing at the runway was significantly reduced

($t(70) = 3.95$, $p < 0.001$, $F(70,70) = 8.38$, $p < 0.001$).

Airborne spacing produced very precise relative spacing at the threshold, and therefore can increase runway throughput

Arrival time accuracy for participating aircraft -all participating arrivals-



Actual– scheduled time of arrival at runway, mean (and standard deviation) in seconds

	FMS/CDA	+Airborne spacing	Total
Arr. Mgmt. Sys.	-2.2 (30.4)	3.3 (53.0)	**0.5 (43.0)**
+ATC tools	4.1 (15.6)	-7.8 (11.1)	**-1.8 (14.7)**
+Data link	13 (37.4)	-0.02 (24.7)	**6.5 (32.1)**
Total	**5.0 (29.8)**	**-1.56 (34.7)**	

- **airborne spacing shows marginally significant lower mean** ***($t_{\text{two-tailed pair-wise}}$: (124) = 1.8; p < 0.07)*.**
- **ATC-tools reduce variability** ***(F(83,81) = 8.53, p <0.001)***
- **Arrival Management System accounts for main effect**

The automated arrival management system was able to organize the arrival flow such that most aircraft arrived within 30 seconds of their arrival time, which was assigned 40 minutes before touchdown

Arrival time accuracy
- all non-participating arrivals -

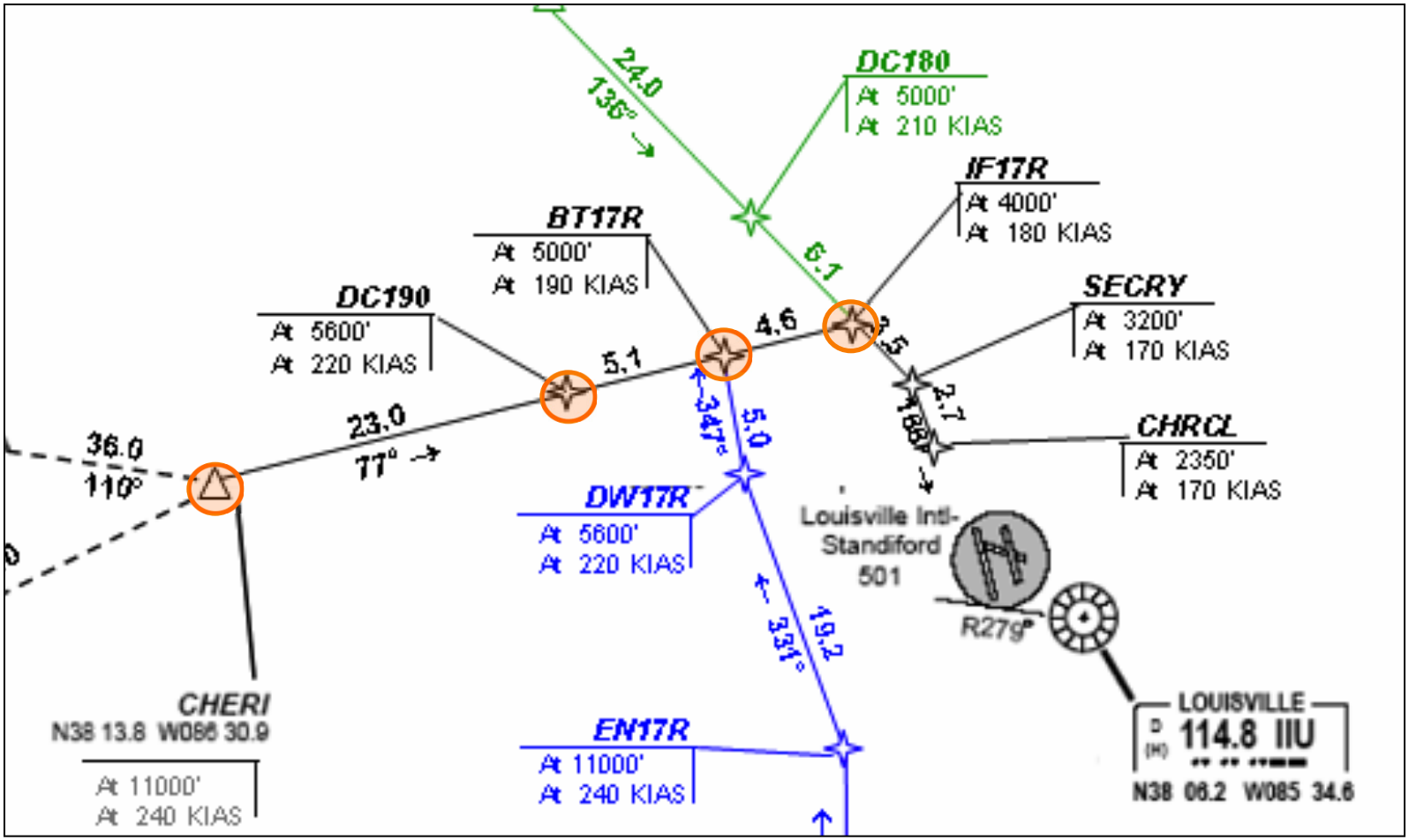
Actual– scheduled time of arrival at runway, mean (and standard deviation) in seconds

	FMS/CDA	+Airborne spacing	Total
Arr. Mgmt. Sys.	-26.2 (52.8)	-28.7 (55.5)	**-27.3 (50.3)**
+ATC tools	-2.1 (27.2)	-0.8 (18.8)	**-1.5 (22.7)**
+Data link	-2.9 (26.0)	-0.7 (33.3)	**-1.8 (29.1)**
Total	**-10.4 (37.9)**	**-9.75 (37.7)**	

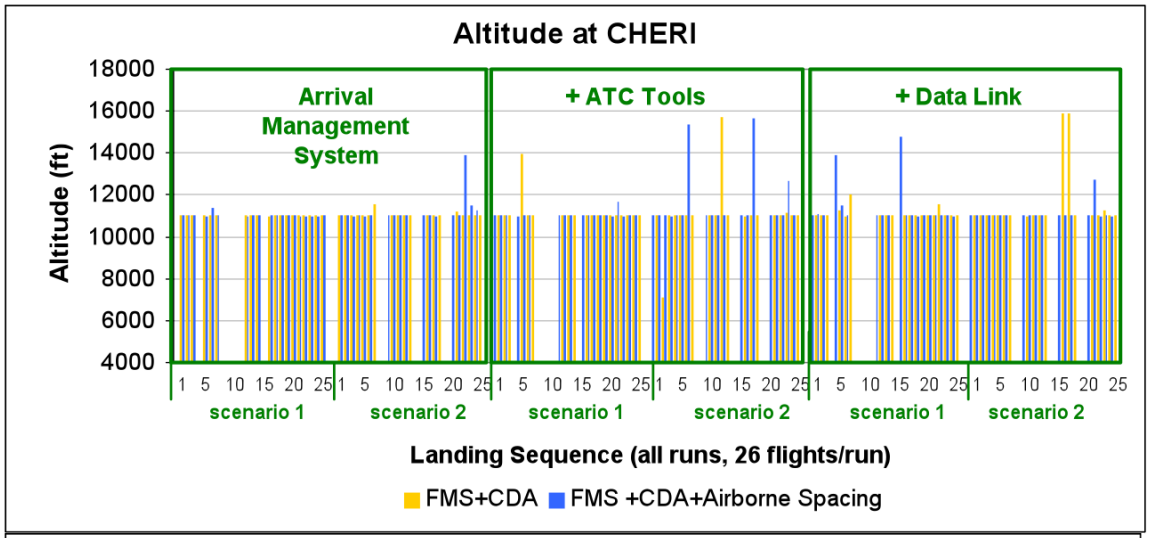
- **No effect of airborne spacing**
- **without controller tools non-participating aircraft arrived on average 26 seconds earlier than in the tools condition *(t (23) = -2.1, p < 0.047*) with a much larger variability *(F (18,39) = 3.8, p < 0.001)***

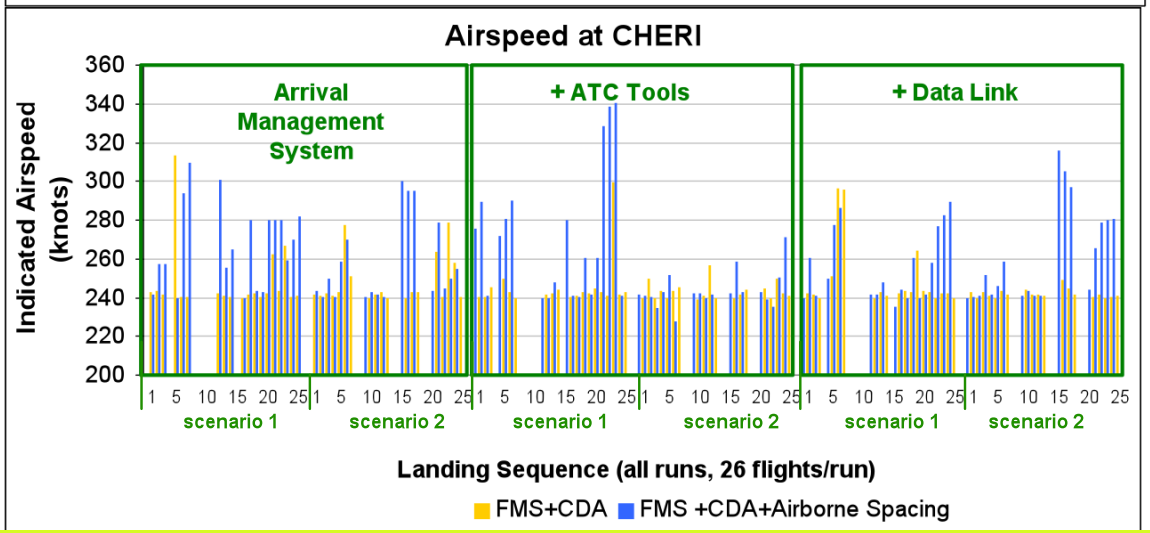
ATC tools connected to the arrival management system enabled controllers to manage the arrival time of non-participating aircraft more precisely

Energy management: from TRACON entry to final turn



Energy management – speed and altitude at CHERI

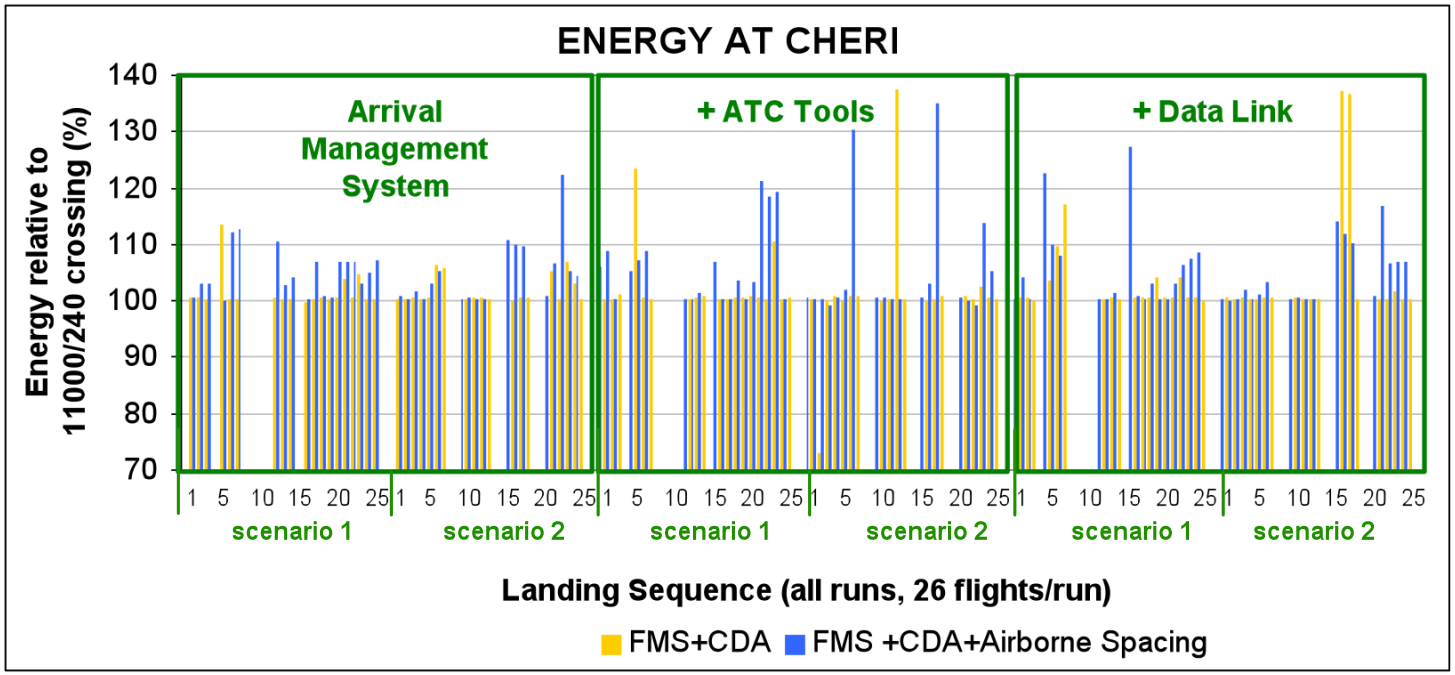




- **Nominal crossing at CHERI was 11000 feet, 240 knots**
- **Controllers and pilots were briefed that airborne spacing speed would take precedence over speed on CDA**
- **Good altitude compliance, peaks indicate problems with getting clearance on time**
- **Speed varies in airborne spacing condition**

Speed adjustments during the initial idle descent portion resulted in aircraft being high or fast at the first crossing restriction

Energy management – Relative energy at CHERI



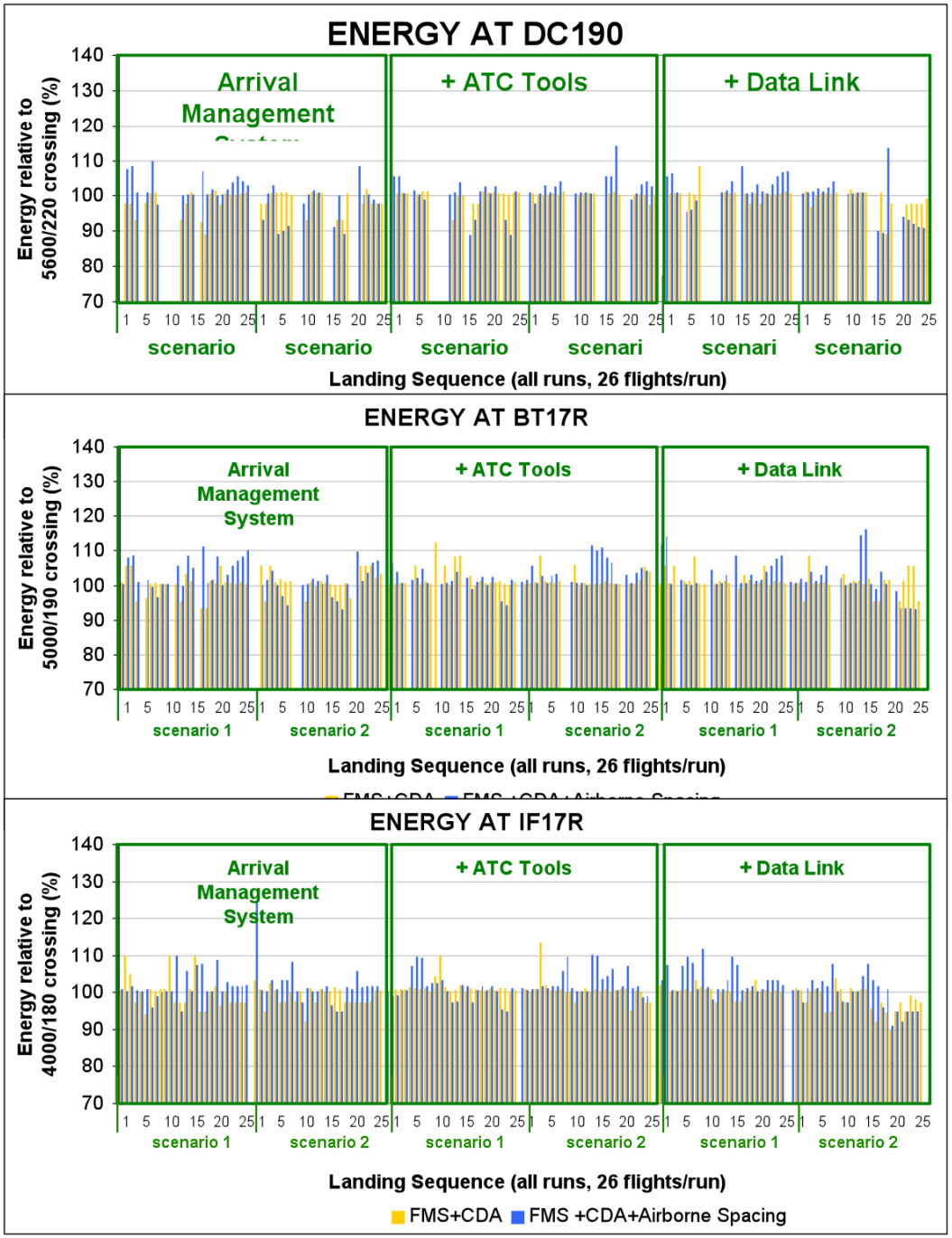
	FMS/CDA	+Airborne spacing	Total
Arr. Mgmt. Sys.	102.2 (2.5)	107.4 (5.1)	**104.8 (4.7)**
+ATC tools	102.5 (5.3)	109.1 (10.0)	**105.6 (8.6)**
+Data link	104.4 (8.9)	107.5 (6.1)	**105.9 (8.1)**
Total	**102.9 (6.1)**	**108.8 (7.7)**	

Relative energy: actual energy as a percentage of nominal energy for CHERI crossing restriction (240/11000)

Aircraft conducting airborne spacing had a significantly higher relative energy mean at CHERI ($t(58) = 4.2$; $p < 0.001$).

Very few aircraft were low on energy, which is typical at the first crossing restriction after an idle descent.

Energy management – Relative energy inside the TRACON

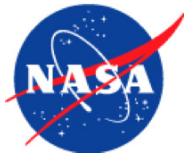


Base turn

Final turn

The CDA's were designed with nominal lower power segments during approach. The excess energy from the initial crossing restriction was largely absorbed downstream of CHERI

Concluding Remarks



- It seems possible to conduct continuous descent arrivals in high density airspace.
- Airborne spacing has positive effect on runway throughput and no negative impact on on-time arrivals.
- The highly automated arrival management concept was very effective in all conditions.
- ATC tools reduce the mean error for non-participating aircraft and reduce the variability of all aircraft.
- Energy management remains a primary issue to be addressed.